Surrogate Modeling of Base Station Exposure

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INTRODUCTION

The World Health Organization (WHO) recently listed in its Research Agenda the need for quantification of the exposure to widespread as well as emerging radio frequency (RF) sources [1]. This information is valuable for both epidemiological research and governmental risk communication towards the general public. However, robust assessment of RF electromagnetic fields (EMF) is not yet possible in real-world situations, because in the current assessment approaches only a limited data set of exposure measurements is available at a given time. The objective of this paper is to conceptualize a new methodology to obtain an accurate and efficient exposure assessment, making it possible to make an accurate map of the exposure to RF-EMF in a certain area, despite an incomplete set of measurements and limited accuracy.

MATERIALS AND METHODS

Our procedure begins with a characterization of the area (determining geo-coordinates and dominant signals), after which a Latin hypercube distribution of the initial measurement locations is calculated. Measurements performed at these locations are used to build a first surrogate model (cubic spline interpolation), and to calculate a next batch of locations, using a sequential sampling algorithm. The measurements are thus performed iteratively: based on the knowledge that becomes available from the previous measurements, this algorithm "learns" the EMF exposure on the fly, and sequentially proposes optimal locations for future measurements. This way the procedure can be stopped at any moment in time, e.g. when a certain stopping criterion is fulfilled. The validation area of this study is a small suburban area (0.04 km^2) in Ghent, Belgium, where we have measured Global System for Mobile Communications base station radiation at 900 MHz (GSM900 downlink) using an EME-SPY120 exposimeter.

RESULTS

We measured the electric-field strength for 10 batches of 10 locations. After each batch, the surrogate model was updated. Table 1 summarizes the model parameters of models M_0 - M_9 (corresponding to 10-100 measurement locations) as well as the average of the sum of the absolute values of the relative deviations of the electric field levels predicted with model i with respect to the ones calculated with model i-1 ($\Delta(M_i,M_{i-1})$). Models M_0 and M_1 (Table 1) show a relatively constant electric-field distribution, with only slight variation, and maximum electric-field values below 0.20 V/m. In models M_2-M_4, several regions with electric-field levels above 0.25 V/m are identified, each time significantly changing the model, and no additional regions are found in the consecutive models. Once the main variations in the field are discovered, $\Delta(M_i,M_{i-1})$ drops below 5%. These results show that in this particular case 50 measurements locations are sufficient to obtain a valuable map of the GSM900 electric-field distribution , and 70 locations are sufficient to completely characterize the exposure. Fig. 1 shows the surface plot of the model built from 70 measurements (M_6).

Validating this model M_6 using 30 independent measurements, we obtained very good results. The mean relative error between model and validation measurements is just 1.5 dB, with more than 83% of the relative errors below 3 dB, as shown in Fig. 2. The correlation is also very good, with Pearson and Spearman correlation coefficients of 0.71 and 0.74, respectively, a linearly weighed κ of 0.51, and a sensitivity and specificity of 0.67 and 0.92, respectively.

CONCLUSIONS

A new, efficient measurement and modeling approach is proposed for the assessment of base station exposure, based on surrogate modeling and sequential design. The proposed method is applicable in real time and without a priori knowledge, making it interesting for epidemiologists, authorities and dosimetry research. The application of our procedure to both other signals as well as to a larger area will be the subject of future research.

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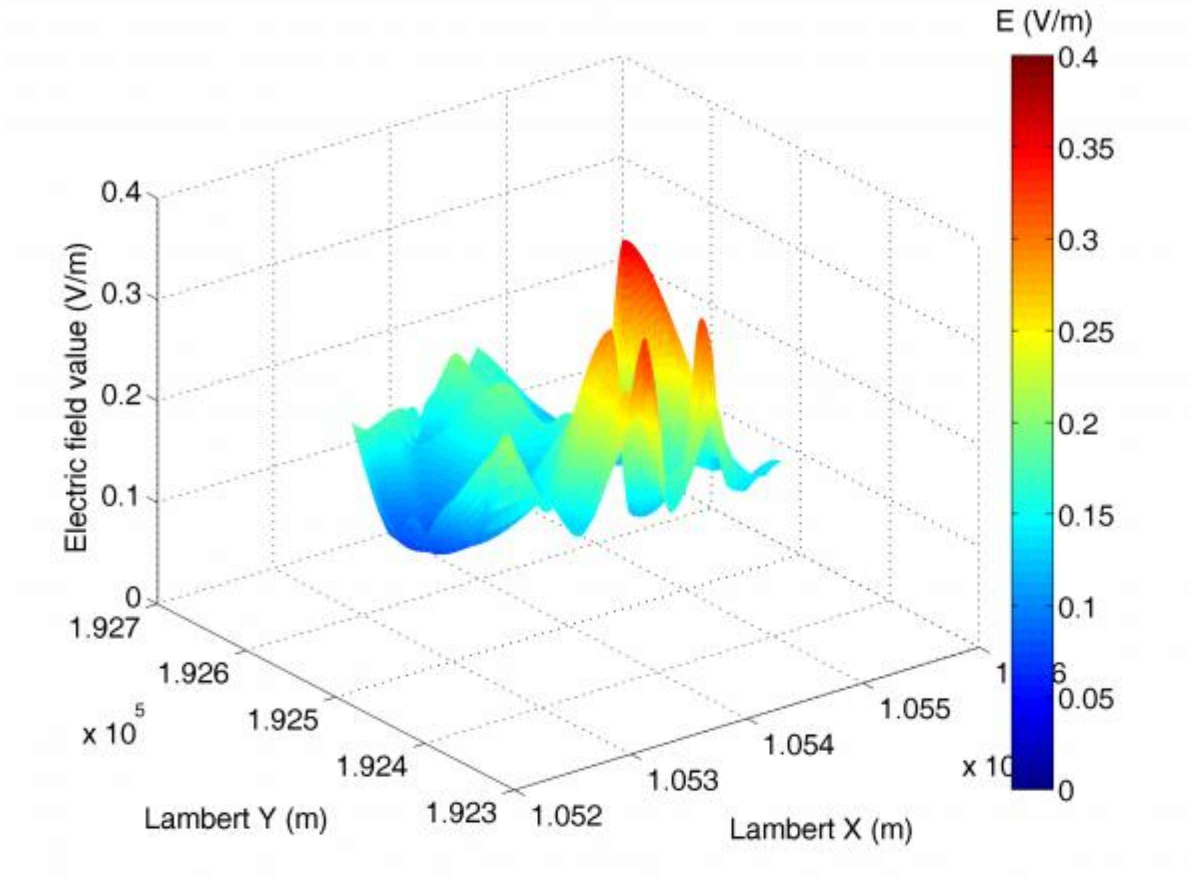

Figure 1.

Surface plot of model of M_6 showing regions of high (peaks) and low (valleys) exposure.. X and Y are Belgian Lambert 1972 coordinates.

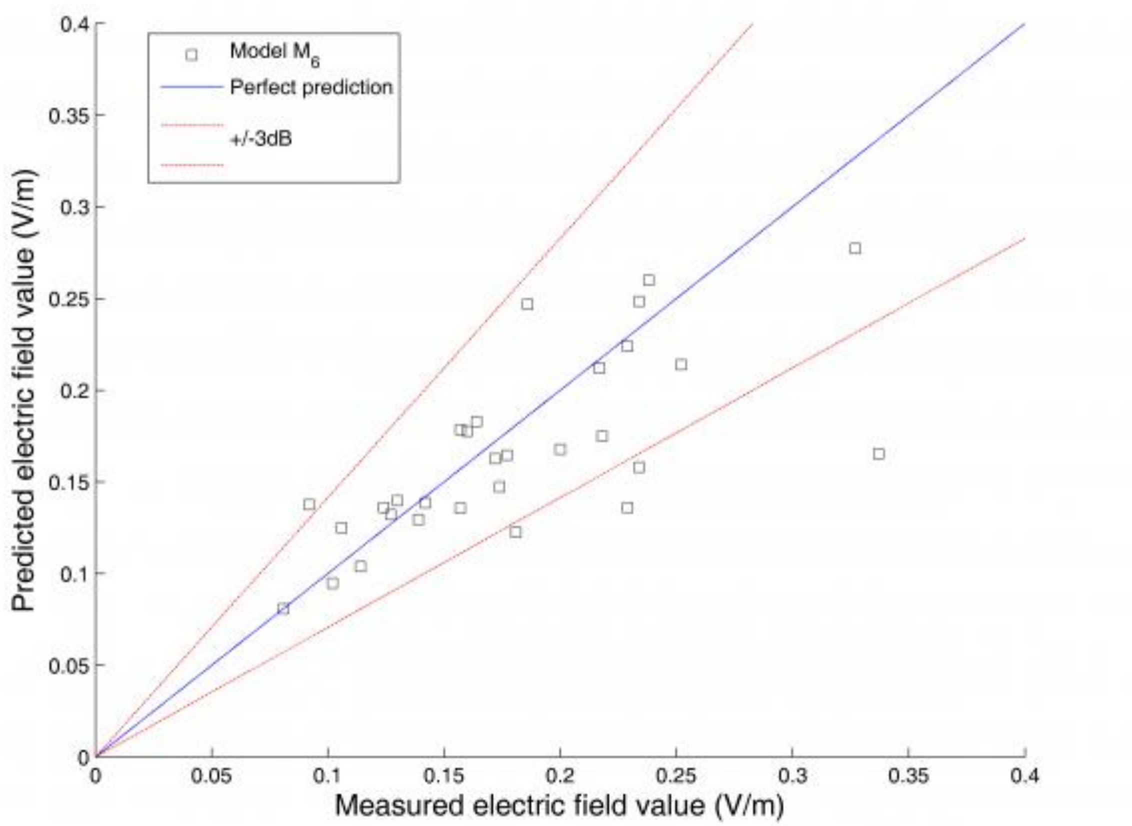

Figure 2.

Comparison of measured and predicted (by model M_6) electric-field values. The full blue line depicts a perfect prediction; the dotted red lines define the region with errors below 3 dB.

Table 1.

Electric-field parameters (mean and minimum-maximum) (V/m) of the subsequent interpolation models and the change of a model (%) compared to the previous one.

Model	E_{avg} (V/m)	E_{min} - E_{max} (V/m)	$\Delta(M_i,M_{i-1})$ (%)
M_0	0.142	0.075 - 0.195	--
M_1	0.151	0.080 - 0.197	8.41
M_2	0.163	0.062 - 0.268	11.88
M_3	0.182	0.071 - 0.345	15.57
M_4	0.187	0.070 - 0.360	5.21
M_5	0.182	0.070 - 0.359	3.20
M_6	0.180	0.069 - 0.360	3.06
M_7	0.181	0.069 - 0.361	2.31
M_8	0.182	0.070 - 0.386	1.56
M_9	0.182	0.070 - 0.384	1.20

E_{avg} is the average, and E_{min} and E_{max} are the minimum and maximum electric-field strengths of a certain model. $\Delta(M_i,M_{i-1})$ is the average of the sum of the absolute values of the relative deviations of the electric field levels predicted with model i with respect to the ones calculated with model i-1.